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99

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Author(s): Jennie A. Richardson
Stuart McKernan
Michael J. Vigil

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Process Hazards Analysis (PrHA) Program, Bridging Accident Analyses and Operational Safety

Jennie A. Richardson, Los Alamos National Laboratory
Stuart McKernan, Los Alamos National Laboratory
Michael J. Vigil, Los Alamos National Laboratory

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Abstract

Recently the Final Safety Analysis Report (FSAR) for the Plutonium Facility at Los Alamos National Laboratory, Technical Area 55 (TA-55) was revised and submitted to the U.S. Department of Energy (DOE). As a part of this effort, over seventy Process Hazards Analyses (PrHAs) were written and/or revised over the six years prior to the FSAR revision. TA-55 is a research, development, and production nuclear facility that primarily supports U.S. defense and space programs. Nuclear fuels and material research; material recovery, refining and analyses; and the casting, machining and fabrication of plutonium components are some of the activities conducted at TA-55. These operations involve a wide variety of industrial, chemical and nuclear hazards.

Operational personnel along with safety analysts work as a team to prepare the PrHA. PrHAs describe the process; identify the hazards; and analyze hazards including determining hazard scenarios, their likelihood, and consequences. In addition, the interaction of the process to facility systems, structures and operational specific protective features are part of the PrHA. This information is rolled-up to determine bounding accidents and mitigating systems and structures. Further detailed accident analysis is performed for the bounding accidents and included in the FSAR. The FSAR is part of the Documented Safety Analysis (DSA) that defines the safety envelope for all facility operations in order to protect the worker, the public, and the environment. The DSA is in compliance with the U.S. Code of Federal Regulations, 10 CFR 830, *Nuclear Safety Management* and is approved by DOE. The DSA sets forth the bounding conditions necessary for the safe operation for the facility and is essentially a "license to operate."

Safety of day-to-day operations is based on Hazard Control Plans (HCPs). Hazards are initially identified in the PrHA for the specific operation and act as input to the HCP. Specific protective features important to worker safety are incorporated so the worker can readily identify the safety parameters of the their work. System safety tools such as Preliminary Hazard Analysis, What-If Analysis, Hazard and Operability Analysis as well as other techniques as necessary provide the groundwork for both determining bounding conditions for facility safety, operational safety, and day-to-day worker safety.

Introduction

Often the question is raised as to the value of formal safety analyses on the day-to-day control of hazardous operations. At Los Alamos National Laboratory operated for the U.S. Department of Energy (DOE) by the University of California, the Process Hazards Analysis program for the Plutonium Facility at Technical Area 55 (TA-55) establishes not only a basis for hazards analyses that are rolled up into a Safety Analysis Report (SAR), but also as input to Hazard

Control Plans that are used in daily operations. The current program has produced over seventy Process Hazard Analyses (PrHAs) that were submitted to DOE with the recently revised SAR in 2002. These PrHAs baseline all process operations within the TA-55 Plutonium Facility. Likewise, operational groups have produced Hazard Control Plans (HCPs) for their operations that are based on the hazards identified, the hazards analyzed and the controls identified in their PrHA to determine risk ranked hazards and discuss how to control these hazards in the work environment.

Background: The Plutonium Facility (PF-4) at TA-55 has been in continuous operation without long-term interruption since its construction in 1978 and is a nuclear material research, development and production facility incorporating numerous processes using a number of radionuclides including ^{239}Pu, ^{238}Pu, highly enriched uranium (HEU) and to a lesser degree other actinides. These activities support nuclear stockpile stewardship and management, nuclear material residue stabilization, waste management, environmental cleanup, advanced nuclear energy concepts, and nuclear material management and safeguards. In addition to DOE programs, PF-4 also supports space missions and produces heat sources used in space exploration.

PF-4 is a Hazard Category 2 DOE facility according to DOE-STD-1027-92, *Hazard Categorization and Accident Analysis Techniques for Compliance with DOE Order 5480.23, Nuclear Safety Analysis Reports*. In reviewing radionuclide inventories contained within PF-4, quantities for radionuclides ^{239}Pu and ^{238}Pu thresholds are exceeded. However, by design, PF-4 contains only small energy sources. Therefore, PF-4 does not have the potential for significant offsite consequences associated with nuclear reactors (Hazard Category 1) and is a Hazard Category 2 nuclear facility. PF-4 handles sufficient quantities of fissile materials to create a potential for an inadvertent nuclear criticality, which is another ground rule in DOE-STD-1027-92 for a Hazard Category 2 nuclear facility.

Under RCRA, TA-55 is permitted to generate, treat and store and transport mixed waste and is required to have an emergency plan according to 40 CFR 264, *Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities.* DOE-STD-1027-92 also defines a Hazard Category 2 facility as having an inventory of hazardous material to warrant onsite emergency planning. TA-55 inventories many hazardous chemicals, some which are close to thresholds specified in 29 CFR 1910.119, *Process Safety Management of Highly Hazardous Chemicals*, requiring process safety analyses. Again the potential consequence from an inadvertent chemical spill or leak is limited to significant on-site consequences defining a Hazard Category 2 facility, but is not a risk to the off-site community.

The initial SAR defining the safety envelope for PF-4 was written in 1978. As a result of new DOE orders and safety initiatives, the PF-4 SAR was substantially revised in 1996 based on DOE Order 5480.23, *Nuclear Safety Analysis Reports*, and DOE-STD-3009-94, *Preparation Guide for U.S. Department of Energy Nonreactor Nuclear Facility Safety Analysis Reports*. The Safety Evaluation Report (SER) issued by DOE in December 1996, as part of the approval process, required the establishment of a "continuous process hazards analysis program consistent with a Process Safety Management approach." Since 1996, over seventy Process Hazards Analyses (PrHAs) have been written and were submitted in 2002 with the latest SAR revision to DOE. The seventy PrHAs represents the ongoing operations that were described and evaluated in the 1996 Hazards Analysis and SAR as well as new operations that have been brought online since then and have been incorporated into the latest SAR revision in 2002.

The Documented Safety Basis (DSA) consists of the SAR, the SER, Technical Safety Requirements (TSRs), PrHAs, and change control documents called Unreviewed Safety Question Determinations (USQDs). The DSA defines the safety envelope for all facility operations in order to protect the worker, the public and the environment. The DSA is in compliance with U.S. Code of Federal Regulations, 10 CFR 830, *Nuclear Safety Management*, and is approved by DOE. This body of documents is the license for the operations conducted at TA-55 PF-4 and is also referred to as the Authorization Basis.

PrHA Development

As previously stated, numerous PrHAs were retroactive for operations that were already being performed at TA-55 and incorporated in the first SAR revision in 1996. The goal, however, of the Process Hazards Analysis program is to examine all operations for safety with the same formal systematic thoroughness. Each PrHA is lead by a safety analyst implementing a team approach that includes safety analyst, operational personnel and as required facility specialists and subject matter experts. The same risk based approach used in the 1996 Hazards Analysis is used in the PrHAs. The purpose of the PrHA is to:

- Baseline processes for Change Control (USQD),
- Provide Risk Ranking for the SAR so Bounding Accidents can be defined,
- Provide Hazards Identification based on risk for HCPs,
- List controls for USQDs, The SAR and HCPs.

Each PrHA describes in detail the operation broken down into process steps and is often flow-charted. Operational layout, equipment, pertinent operating parameters as well as material at risk are included in the process steps. Interfaces such as facility systems and material movement are defined. Hazards for the operation are identified using a checklist. The information gathered is similar to information used in Preliminary Hazard Analysis.

Hazards are then evaluated usually using the "What If" analysis method as described in the AIChE *Guidelines for Hazard Evaluation Procedures* (Ref.1). Other evaluation methods can be used, but this method is very conducive to evaluating hazards within each specific process step by imagining what could go wrong and reduces assumptions about the way things "should work or should be done." An example is: "What If" the sample can is dropped and the lid pops off. The method is not linear and allows brainstorming of several different types of failures for each process step. Determining an ultimate consequence for each scenario allows further evaluation based on a graded approach. Controls and barriers preventing each scenario are also listed. A completed "What If" Table includes:

- The "What If" question,
- The worst case consequence,
- Safeguards, controls or methods of prevention,
- Response to the "What If" such as "notify group office,"
- Action items and comments.

Operational personnel are key to the success and completeness of the "What If" Table while the safety analyst can often assist with "pulling the string" for scenarios and assuring that all identified hazards have been addressed.

After the "What If" Table is created based on process steps, risk ranking is performed. Each scenario that has a consequence to the worker, public or environment is then evaluated in a qualitative manner without taking credit for any mitigation. LA-UR-02-6229, *Quantitative Criteria for Categorization of Hazards at Nuclear Material Technology Division Facilities* (Ref.2), in addition to providing quantitative criteria for categorization of nuclear, toxic, carcinogenic and pressure wave hazards also provides some qualitative criteria especially useful for determining worker doses that quantitatively are very difficult to calculate. The bases for some qualitative estimates are also derived from previously calculated consequences from similar scenarios in other PrHAs or the SAR. Consequences are then ranked by assigning an alphabetical category A through D with A being the most severe. Table 1 lists the severity categories for each target group: the worker, the public and the environment.

Table 1- Consequence Severity Categories

Category (C)	Public (P)	Worker (W)	Environment (E)
A	Immediate health effects, $\geq$25 rem	Loss of life, or > 400 rem	Significant off-site contamination requiring cleanup.
B	Long-term health effects, 5rem $\leq$x <25 rem	Severe injury or disability, 5rem < x < 400 rem	Moderate-to-significant onsite contamination. Minor offsite contamination.
C	Irritation or discomfort but no permanent health effects, 100 mrem $\leq$ x<5 rem	Lost-time injury but no disability, 1 rem < x < 5 rem Radiation uptake or dose causing temporary radiation worker restriction	Significant contamination of originating facility. Minor onsite contamination. No offsite contamination.
D	No significant offsite impact, <100 mrem	Minor or no injury and no disability, < 1 rem	Minor or no contamination of originating facility No onsite contamination No offsite contamination

Scenarios that have no consequence to the worker, the public or the environment are not evaluated further. These scenarios often have consequences involving the quality of the product and may be addressed by the operating group in a separate quality evaluation.

When all the unmitigated consequences for the relevant scenarios in the "What If" Table are determined, frequency is evaluated. The frequency of scenarios in most circumstances is again a qualitative evaluation, but for some scenarios such as power outage actual data may exist. Data may be taken from TA-55 Facility Operating Logs, observations from walk-arounds or self-assessments, or the ORPS (Occurrence Reporting and Processing System) database. DOE has a state-of-the-art accident investigation program that evaluates root causes for off normal occurrences in DOE facilities throughout the complex and publishes them in the ORPS database available online to DOE contractors and personnel.

Some frequencies may depend on a series of failures occurring since consequences are determined without taking credit for any mitigative controls. An example is a fire scenario where mitigative controls such as sprinkler system and ventilation are assumed to fail when determining the consequence of a fire. Probability failures determined in previous quantitative evaluations such as event trees, fault trees, probability analyses, and other quantitative methods used in the SAR and supporting analyses can be used as PrHA resources. All scenario frequencies within the PrHA are assigned a qualitative estimate and Roman numerals starting at I to V are used. Roman numeral I is the most frequent defined as occurring as frequently as normal operations (1) to once in 10 operating years or once a year in 10 similar facilities (10^{-1}). Roman numeral V is less than 10^{-6} or less than one in 1 million years occurrence. The frequency categories are listed in Table 2.

Table 2- Frequency Categories

Frequency	Definition
I (1 to 0.1)	Normal Operations: frequency as often as once in 10 operating years or at least once in 10 similar facilities operated for 1 yr.
II (0.1 to .01)	Anticipated Events: frequency between 1 in 100 yr and one in 10 operation years or at least once in 100 similar facilities operated for 1 yr.
III (10^{-2} to 10^{-4})	Unlikely: frequency between 1 in 100 yr and 1 in 10,000 operating years or at lease once in 10,000 similar facilitated operated for 1 yr.
IV (10^{-4} to 10^{-6})	Very Unlikely: frequency between 1 in 10,000 yr and once in 1 million years or at least once on a million similar facilities operated for 1 yr.
V ($< 10^{-6}$)	Improbable: frequency of less than once in 1 million years.

Controls listed in the "What If" Table are determined to be:

- Protective features that are inherent to the operation such as high temperature shut-off of equipment,
- Protective systems that are part of the facility such as ventilation, and
- Administrative controls such as the emergency response program or training.

Scenarios are risk ranked and grouped to find representative sequences and reduce redundancy. Risk rank is the combination of consequence and frequency (see Table 3). Sorting is done first considering consequences for a given set of scenarios and then frequency. The most severe consequences are given higher priority even if frequency is low. Selection and roll-up of scenarios is explained within the PrHA.

A Hazards Analysis Table is created from the representative sequences listing the risk, frequency, consequence; activity code (based on process step); cause/scenario; consequence to the public, the worker, and the environment; and controls based on whether they are protective features, protective systems, or administrative controls. The Hazards Analysis Table is the culminating result of a largely qualitative evaluation of all hazards involved for a given operation and is the decision tool for what further analysis is required. The Hazards Analysis Table reflects the breath of analysis within the PrHA, which is the main goal in examining the all the potential failures of a process. Typical industrial type accidents are not evaluated further unless a process unique aspect compounds them. OSHA standards are adhered to within PF-4. Table 3 is then use to determine the risk ranking for each scenario.

Table 3- Risk

Severity of Consequence	**Likelihood of Consequence**				
	I	**II**	**III**	**IV**	**V**
A	1	1	2	3	3
B	1	2	2	3	4
C	1	3	3	4	4
D	3	4	4	4	4

If scenarios emerge that have high-unmitigated consequences, further quantitative analysis may be required as part of determining Bounding Accidents. Not all PrHAs require determining a Bounding Accident Assessment if consequences are Cs and Ds and risk rank is 3 and 4, they are low hazard operations and further evaluation is not required. Examples of scenario groups with high consequences are:

- Radiological material releases such as contamination released from gloveboxes,
- Chemical releases such as spills,
- Fires,
- Deflagrations/explosions, and
- Criticality.

For high consequence scenarios a Bounding Accident Assessment is performed in the PrHA. For each consequence requiring a Bounding Accident Assessment the scenario is developed in detail defining material at risk, the damage ratio, airborne release fraction, respirable fraction, leak path factor, source term, and the ultimate unmitigated consequence in a quantifiable form usually as dose to Maximally Exposed Offsite Individual (MEOI) since radiological material releases and fires dominate. Other quantifiable consequences may be a pressure wave or chemical concentration from which a health or environmental affect can be determined.

Since the consequence in unmitigated cases often assumes a series of failures of barriers such as containers, gloveboxes, ventilation, and fire suppression system; event tree analysis is a good tool to use. This provides a basis for what realistic mitigated consequences should be as well as the relative importance of the barriers evaluated. Only a select list of barriers should be identified in the event tree that have engineering surveillance, strict design criteria or both since these barriers will have safety significance and have additional safety and quality requirements.

The final sections of the PrHA discuss the controls identified as protective features for the operation, protective systems provided by the facility, and process specific administrative controls. These sections demonstrate how these controls reduce the hazards encountered within the operation. As stated above, only a select list should be attributed with reducing consequences and the remainder will be defense-in-depth or best business practices.

Input from PrHAs into SAR Development

Hazards Analysis for a SAR requires the accumulation and processing of information on a multitude of processes. Information that must be defined and integrated includes:

- Hazardous material quantity, form and location,
- Energy sources and potential initiating events,
- Preventive features (any structure, system, or component that serves to prevent a release of hazardous material in an accident scenario-generally passive barriers such as confinement),
- Mitigative features (any structure, system, or component that serves to mitigate the consequences of a release of hazardous material in an accident scenario-passive or active features such ventilation)

The Process Hazards Analysis program systematically evaluates the above information for each process.

The main information extracted from the PrHA and used in the SAR is the Process Description, Hazards Analysis Table, Accident Analysis and Controls. The PrHA also provides the logic; the rational and details of how and why certain scenarios are selected and which ones become Bounding Accidents. This is the breath of analysis required to evaluate all the hazards within a complex facility such as PF-4. This in turn defines the types of additional analyses such as Failure Modes and Effect Analysis (FMEA), Event Tree Analysis (ET), Fault Tree Analysis (FT), Hazard and Operability studies (HAZOP) and computer codes needed to attain an in-depth understand of accident phenomena and progression. By having used a graded approach, the in-depth analysis is performed on the most significant scenarios that define the Bounding Accidents and therefore the safety envelop for the facility. The PrHA program does evaluate global hazards such as earthquake so these hazards are analyzed separately to define Bounding Accidents using seismic analysis.

The 1996 Hazards Analysis evaluated over 800 scenarios that were used to determine the Bounding Accidents for the 1996 SAR revision. Evaluation of the PrHAs for the 2002 SAR revision looked at close to two thousand scenarios, over twice as many scenarios developed in the seventy plus PrHAs in the six years preceding the latest SAR revision in 2002. Some changes had occurred in operations within TA-55 between 1996 and 2002, but budget and MAR have essentially been constant over the six-year period. Types of dominate accidents have not changed. Spills or Accidental Releases are dominant hazards in both the 1996 Hazards Analysis and 2002 SAR revision. Criticality accidents are risk ranked 2 accidents, but small contributors to the overall accidents in the risk rank 2 category. Risk distribution has changed with higher percentage of unmitigated risk found in risk rank 1 and 2 catagories in the 2002 SAR.

One difference in the approach between the hazards analysis and roll-up efforts for the two SAR revisions is time. The 1996 Hazards Analysis was conducted from September 1993 through mid-

February 1994, less than a year. The latest 2002 SAR revision is based on seventy PrHAs written over six years. This reflects the advantage of a formal systematic Process Hazards Analysis program that looks at all options to capture the breadth of potential hazards. It also reflects the learning curve that both safety analysts and operational personnel have undergone in recognizing and analyzing hazards. Table 4 compares the 1996 Hazards Analysis and 2002 SAR revision risk distributions.

Table 4-Comparison of Risk Rank between the 1996 Hazards Analysis and 2002 SAR

Risk Rank	Percent in 1996 Hazards Analysis	Percent in 2002 SAR Revision
1	0	0.63%
2	3.5%	19.34%
3	60.4%	60.43%
4	36.1%	19.6%

Input from PrHAs into HCP Development

Prior to the mid-1990s, operational groups wrote Safe Operating Procedures (SOPs) that were a combination of hazards identification and process work steps. LANL initiated a Laboratory wide integrated safety program in the 1990s that resulted in the separation of hazard control and work instructions. The result was a risk based hazards identification and controls document for operations that were called Hazard Control Plans (HCPs). Specific work instructions were addressed in separate documents.

HCPs can address individual processes or umbrella several processes with common hazards. For a process specific HCP, a Description of Work is written that often is similar to a summary of the process description in the PrHA. Hazards are then discussed by listing the activity where the hazard may be encountered; the type of hazard; the initial risk (both consequence and probability); description of how the worker is exposed to the hazard; the controls in place to mitigate the hazard; and finally the residual risk with the controls in place. Emergency actions; waste management; and required skills, knowledge, and abilities (training) complete the text of the HCP. The consequence evaluation is only to the worker and potentially the environment, but does not consider the public. A Hazard Screening Checklist is presented in the appendix listing the type of hazard and how it is encountered, initial risk, controls, and residual risk.

TA-55 was fortunate that both the PrHA and HCP programs were initiated in the same approximate time period. This allowed for information gathering that had to be used in both documents to be shared. The formal risk ranking in the PrHA can be used as initial risk with modification in the HCP. Controls that are process specific identified in the PrHA are incorporated into the HCP. The HCP assumes that facility protective systems are operable even when determining initial risk so the initial risk in an HCP is more reflective of the mitigated case in a PrHA. This is reasonable since operations would not occur if facility systems were off normal.

The qualitative evaluation of consequence and frequency used in HCPs is broader and not as specific as in PrHAs. Consequences are not separated out by target group or given specific quantities such as those listed in Table 1. Consequences are categorized as: Catastrophic, Critical, Moderate, and Negligible. An example is the definition for Catastrophic: Death, severe injury/occupational illness, severe environmental harm or liability, or severe property damage, unrecoverable adverse impact to mission-critical facilities. Probability is ranked as Frequent (I), Probable (II), Occasional (III), Improbable (IV), and Remote (V). The Roman numeral in parenthesis is the PrHA counterpart shown in Table 2. Again an example for the definition of frequency is Remote: highly unlikely to extremely unlikely.

Both PrHA and HCP are living documents and should compliment each other for the life cycle of the process. It is expected that as processes change, both the PrHA and HCP documents will be updated. Some operations have already revised their PrHAs.

Lessons Learned

As to be expected with the maturing of any program, lessons are learned and implemented. One of the goals to be implemented in the near future is facilitating SAR annual updates as PrHAs are modified. Another aspect that is related to the SAR is standardizing Hazards Analyses so similar numerical values are used when new PrHAs are written and old PrHAs are revised. LA-UR-02-6229, (Ref.2), was written to standardize consequence calculations and provide guidance. A set of probabilities used in the SAR has been compiled in table format and will be updated as pertinent data is discovered. This will also facilitate rollup of Hazard Analyses when the SAR is revised in the future.

Review of current PrHAs will soon be under way after prioritizing is completed. PrHAs will be reviewed and revised as necessary on a two-year cycle. The goal is to make sure the usefulness of PrHAs continues to feed into HCPs and that process changes are reflected in both documents. HCPs will still be the responsibility of the operating groups, but both will be compared to assure that new findings in one is reflected in the other.

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Biography

J. A. Richardson, Los Alamos National Laboratory, P.O. Box 1663 MS-E578, Los Alamos, NM 87545, USA, telephone - (505) 665-4163 , facsimile - (505) 665-8978, e-mail - jarichrardson@lanl.gov

Jennie A. Richardson is currently part Authorization Basis Group in the Nuclear Materials Technology Division of Los Alamos National Laboratory. She has worked for Los Alamos National Laboratory for the past fourteen years in safety analysis, authorization basis development, safety question determinations, risk assessment, operational safety, and severe accident analysis. Prior to working for Los Alamos National Laboratory Ms. Richardson worked for a consulting firm providing safety analysis expertise to The Department of Energy. Ms. Richardson has a BS in Biology, an MS in Biochemistry and an MS in Nuclear Engineering.

S. McKernan, Los Alamos National Laboratory, P.O. Box 1663 MS-E578, Los Alamos, NM 87545, USA, telephone - (505) 667-7501 , facsimile - (505) 665-8978, e-mail - mckernan@lanl.gov

Bio will be coming: Stuart is Deputy Group Leader of the Authorization Basis Group in the Nuclear Materials Technology Division of Los Alamos National Laboratory.

M. J. Vigil, Los Alamos National Laboratory, P.O. Box 1663 MS-E578, Los Alamos, NM 87545, USA, telephone - (505) 667-0164 , facsimile - (505) 665-8978, e-mail - mjvigil@lanl.gov

Michael J. Vigil is currently the Team Leader for the Unreviewed Safety Question and Hazard Analysis Team at LANL's Plutonium Facility. He has over 15 years of experience in project management, safety analysis, authorization basis development, nuclear weapon stockpile stewardship initiatives, unreviewed safety question determinations, and risk assessment and management at several nuclear facilities throughout the Department of Energy Complex. Mr. Vigil has a BS in Biomedical Engineering and an MS in Industrial Engineering.